Journal of Biotechnology and Natural Science
Vol. 5, No. 1, June 2025, pp. 21-32
ISSN 2808-2508

Characteristics and Diversity of Riparian Plant Species in Relation to Plastic Litter Entrapment in the Bedog River, Indonesia

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ARTICLE INFO

Article history
Received: April 23th 2025
Revised: May 21th 2025
Accepted: May 22nd 2025

Keywords
Bamboo
Plastic piece
Poaceaea
Riverbank vegetation
Yogyakarta river

ABSTRACT

The increasing production of waste and inadequate waste management on land have led to significant plastic leakage into river systems. Riparian vegetation is now increasingly covered by plastic debris, posing a threat to essential biological processes such as pollination and plant metabolism. The aim of this study is to identify the characteristics and types of riparian plant species that trap plastic litter along the riparian zones. The research was conducted in Indonesia, specifically in Yogyakarta Province, which is currently facing a waste management crisis. Bedog River was selected as the sampling site due to its course through densely populated areas, including Sleman and Bantul Regencies. A total of 20 sampling plots, spaced one to two kilometers apart, were distributed along the river, with each plot containing a 25-square-meter sampling plot designated for plant identification. In total, 78 plant species, predominantly from the Poaceae, Moraceae, and Fabaceae families, were found to trap plastic debris. Branches and twigs were the most frequently affected plant structures. Bamboo and shrubs exhibited distinctive morphological characteristics that facilitated plastic entrapment, particularly of small plastic fragments. A substantial portion of riparian vegetation along the Bedog River is covered with plastic waste, necessitating targeted conservation efforts for affected species.

How to Cite: Utami, I. & Tanaka, N. (2025). Characteristics and Diversity of Riparian Plant Species in Relation to Plastic Litter Entrapment in the Bedog River, Indonesia. *Journal of Biotechnology and Natural Science*, 5(1): 21-32.

1. Introduction

Riparian ecosystems provide essential functions in maintaining environmental balance. Positioned at the interface between terrestrial and freshwater ecosystems, they are often recognized for their role in filtering harmful compounds originating from human activities on land before these pollutants enter river systems (Dufour et al., 2018; Wang et al., 2021). Additionally, riparian ecosystems contribute to carbon sequestration, oxygen production, and support high biodiversity, as they are inhabited by organisms adapted to both ecosystems (Dybala et al., 2019; Graziano et al., 2022). Over the past decade, the proliferation of open dumping landfills has been exacerbated by the failure of local governments in developing tropical countries to effectively manage and recycle waste (Macleod et al., 2021). The leakage of terrestrial waste into riverine ecosystems poses a significant threat to the sustainability of riparian vegetation. Notably, 81% of litter found in vegetated riparian zones consists of macroplastic (>5 cm), predominantly fragments and film (Cesarini & Scalici, 2022). Plastics, derived from fossil hydrocarbons, have the potential to become a significant source of anthropogenic carbon in the environment, with an estimated 19 to 23 million metric tons entering aquatic ecosystems annually via river networks (Bruge et al., 2018; Borrelle et al., 2020; Dees et al., 2021). Plastics are composed of strong polymers and are widely utilized across various industries, including packaging, food and beverage appliances, construction and household goods, agriculture and horticulture, automotive and electrical applications, as well as the textile industry (Indonesian Ministry of Environment and Forestry, 2020; Lange, 2021; Taak et al., 2024). Research on plastic pollution in river ecosystems has largely focused on mitigating plastic litter in aquatic environments, mangroves, and marine systems. However, plastic accumulation on riparian vegetation can reduce reproductive success by up to 80% (Gallitelli & Scalici, 2023). As primary producers, plants play a fundamental role in global food webs, and plastics trapped on plant structures have a high potential to enter the food chain (Provencher et al., 2019). Complex plant architectures, particularly those with extensive branching, are more likely to entangle and retain plastic debris transported by river currents (Gallitelli et al., 2023).

To date, relatively few riparian locations have been investigated for their role as effective traps for plastic litter in river ecosystems. Similar studies have been conducted in Italy (representing a developed country) (Cesarini & Scalici, 2022; Gallitelli et al., 2024) and in Vietnam (a tropical developing country), although the latter focused solely on the role of water hyacinth in trapping plastic waste in the Saigon River (Schreyers et al., 2024). Indonesia, as the country with the second-highest contributor of plastic leakage to marine, estimated 0.48 million metric tons per year (Jambeck et al., 2015), presents an interesting case study. This is further supported by the fact that Indonesia is the world's fourth most populous country (Worldometer, 2025), with much of its population concentrated near riverbanks. This high level of plastic leakage exacerbates plastic pollution in the Indian Ocean, which directly borders southern Indonesia. One of the regions facing a severe waste crisis in southern Indonesia is Yogyakarta Province, where daily waste production reaches nearly 2,000 tons (BPS Prov DIY, 2024). The aim of this study is to identify the characteristics and types of riparian plant species that trap plastic litter along the riparian zones of rivers in Yogyakarta, Indonesia. Documenting riparian species involved in plastic entrapment represents a crucial step toward riparian ecosystem conservation and the mitigation of plastic pollution along coastal and marine environments, which serve as the final destinations for terrestrial waste transported by rivers.

2. Methods

2.1. Sampling location

This study employs a quantitative research approach with an exploratory methodology. The Bedog River was selected as the sampling site due to its course through densely populated areas of Yogyakarta Province, specifically Sleman and Bantul Regencies, which have a population density of approximately 2,000 people/km². Waste generation in these regencies is notably high, with 703 tons/day in Sleman and 518 tons/day in Bantul as recorded in 2022 (DLH Sleman, 2023). A total of 20 sampling plots, spaced one to two kilometers apart, are distributed along the 55.3 km stretch of the Bedog River (Figure 1). Within Sleman Regency, the river extends for 32 km, originating from the slopes of Mount Merapi and flowing through the districts of Gamping, Godean, Mlati, Sleman, and Turi. The remaining 23.3 km traverse the districts of Kasihan, Bantul, Pandak, and Pajangan before the river merges with the Progo River in Bantul Regency. The Bedog River watershed (DAS Bedog) is commonly utilized for agriculture, residential areas, office and industrial buildings, as well as tourism activities.

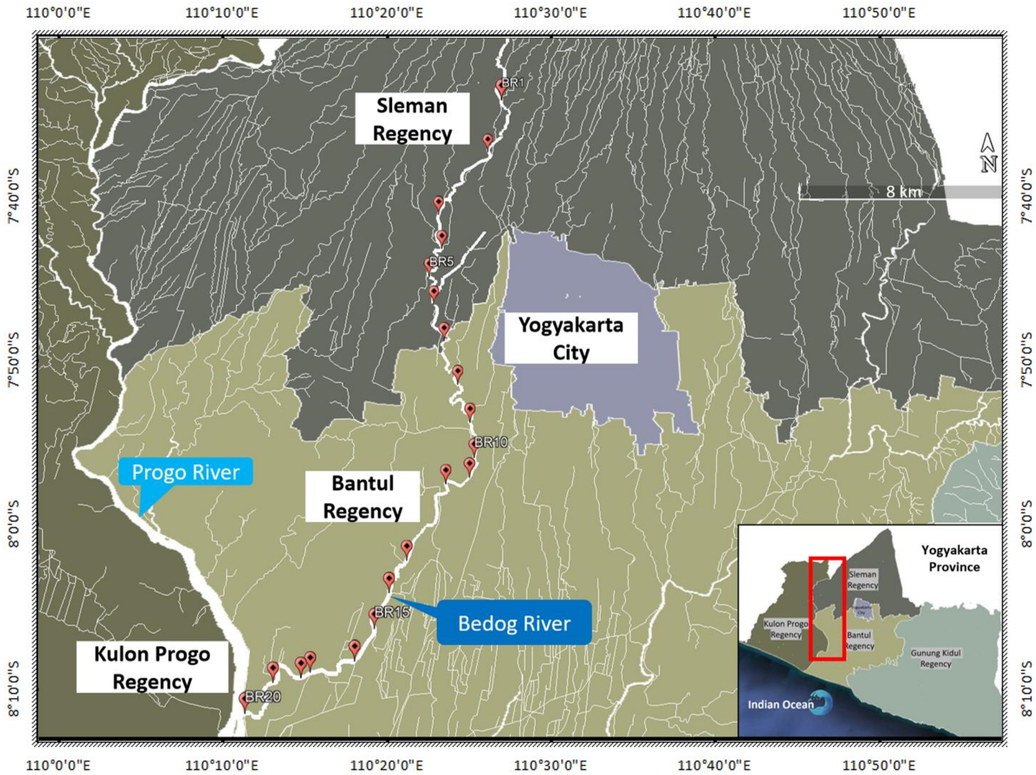

Figure 1. Sampling plots along the Bedog River traversing Sleman and Bantul Regencies in Indonesia

2.2. Sampling methods and data analysis

Sampling was conducted between August and September 2024, coinciding with the end of Indonesia's dry season. At each sampling site, a 5 × 5-meter plot (length parallel to the river flow × width extending inland) was established for plant identification. The name of species, the part of vegetation that traps the plastic (leaves, trees, tendrils, branches, base of steam, root, grass leaves, rhizomes, leaf branch litter), along with river characteristics such as river width, and water flow velocity. The plastic debris analyzed in this study consists of mesoplastics and macroplastics larger than 5 mm in size (van Emmerik & Schwarz, 2020). Water flow velocity was measured using a ping-pong ball method, where the time taken for the ball to travel one meter along a measured distance was recorded. The degree of plastic litter coverage within the 50 m² plot was classified into five levels:

Level 1: Plastic waste covers <20% of the plot area
Level 2: Plastic waste covers 21%–40% of the plot area
Level 3: Plastic waste covers 41%–60% of the plot area
Level 4: Plastic waste covers 61%–80% of the plot area
Level 5: Plastic waste covers >81% of the plot area

The diversity of riparian vegetation was described to illustrate plant species capable of entrapping plastic debris in the river system. Quantitative analysis of riparian vegetation diversity was presented in the form of tables, bar charts, and pie charts. Furthermore, the plastic entrapment potential of each riparian plant species was evaluated using the following formula:

$$\text{Plant} - \text{Plastic entrapment probability} = \left(\frac{\text{Total number of plots where the species was found}}{\text{Number of plots where the species trapped plastic}}\right) \times 100\% \qquad (1)$$

3. Results and Discussion

Based on field measurements, Bedog River has a channel width ranging from 1 to 5 meters, with an average width of 3.26 ± 1.28 meters. The narrow width of this river is due to data collection being conducted at the end of the dry season, which caused the water discharge to decrease. At the time of data sampling, the average air temperature was recorded at around 26.5^{o} C, and the precipitation ranged from 0 to 100 mm (low scale). In terms of landscape characteristics, the riparian vegetation is classified into four dominant vegetation communities: bamboo-dominated, herb-dominated, a combination of bamboo and herbs, and mixed vegetation habits (Figure 2). Among these, bamboo-dominated (50%) landscapes were the most prevalent across all sampling plots, followed by mixed vegetation (30%), which consists of trees, bamboo, herbs, and shrubs within one area. During the sampling period, the average water flow velocity was recorded at 9.84 ± 7.29 s/m (Table 1). Based on field observations, the average plastic litter coverage across all sampling plots was classified as Level 3, indicating 41%–60% plastic coverage. However, in bamboo-dominated riparian area, plastic litter coverage was notably higher, reaching Level 4. At the end of the dry season, river flow slows down, which is expected to increase the accumulation of plastic debris trapped in riparian vegetation over time. Previous research has indicated that 1,309 rivers in Indonesia contribute to the annual plastic emissions into the ocean, with small rivers traversing urban areas being a priority for monitoring (Meijer et al., 2021; Cesarini & Scalici, 2022). Given its narrow width, its course through urbanized areas in the two most densely populated regencies of Yogyakarta Province, and its role as a tributary of the Progo River, the Bedog River should be prioritized for monitoring due to its relatively high plastic pollution levels.

Figure 2. Distribution of vegetation dominance in the Bedog River Riparian zone: (a) Bamboo-dominated, (b) Herb-dominated, (c) Bamboo-Herb combination, (d) Mixed vegetation

Table 1. Information on the Bedog River and riparian area conditions

Parameters	Range	Average
River width	1 m – 5 m	3.26 ± 1.28 m
Average water flow velocity	2 s/m – 30 s/m	9.84 ± 7.29 s/m
Average plastic litter coverage in the riparian area	Total level 1 – 5 bamboo-dominated level 1-5 herb-dominated level 2-3 bamboo and herbs level 3 mixed vegetation level 1-3	Total Level 3 bamboo-dominated level 4 herb-dominated level 2 bamboo and herbs level 3 mixed vegetation level 3

Exploration along the riparian zone of the Bedog River, Yogyakarta, revealed a diverse range of vegetation with plastic debris adhered to various plant structures. A total of 95 plant species from 46 families were initially identified growing in the riparian area. However, only 78 species from 34 families (82%) were observed to effectively entrap plastic waste, as evidenced by plastic fragments attached to their surfaces. The Poaceae, Moraceae, and Fabaceae families were the most frequently encountered along the riparian zone and were identified as key taxa capable of trapping plastic debris (Figures 3a, 3b).

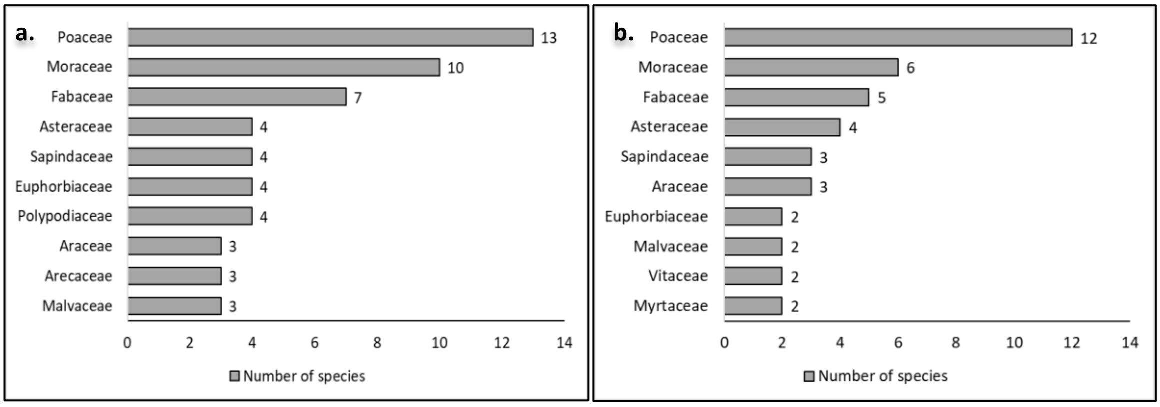

Figure 3. (a) Plant families with the highest number of species growing in the riparian of Bedog River; (b) Plant families and number of species that capable of entrapping plastic debris.

The Poaceae family, comprising grasses and bamboos (giant grasses), was present in all sampling plots and consistently demonstrated plastic-trapping capabilities. Several bamboo species, including *Bambusa spinosa*, *Dendrocalamus asper*, *Bambusa vulgaris*, *Dendrocalamus giganteus*, and *Bambusa multiplex*, exhibited a plastic entrapment potential ranging from 82% to 100% (Table 2). Bamboo is a native riparian species in Indonesian river ecosystems (Widjaja, 2001; Maulana et al., 2022). Its dense clumping structure and numerous branches create a natural barrier that effectively traps plastic debris carried by the river, particularly when the culms bend toward the water. Additionally, bamboo possesses high strength and elasticity, enabling it to withstand riverbank erosion while retaining plastic litter for extended periods (Abdullah et al., 2017). Notably, *Bambusa spinosa* (Figure 4a), which was identified in the riparian zone of the Bedog River, has thorny branches, further increasing the likelihood of snaring and fragmenting plastic materials into smaller pieces (Ervianti et al., 2019). Other members of Poaceae, such as *Cenchrus purpureus* (elephant grass) and *Saccharum officinarum* (sugarcane), also exhibited a 100% plastic entrapment potential and were the most commonly found herbaceous species across all sampling plots. These species are widely distributed worldwide, including across Indonesia, and are known for their adaptive growth, drought tolerance, and suitability for riparian environments (Ray et al., 2018; Arisandi et al., 2019; Ranomahera et al., 2020). As perennial tall grasses that can reach 4 meters in height, their deep root systems and robust rhizomes contribute to high canopy density, which enhances their ability to trap plastic debris in riparian zones due to high canopy density (Pandey et al., 2015; Tulu et al., 2021).

Other species, namely *Ficus hispida* (Figure 4b), *Ficus septica* (both members of the Moraceae family), *Leucaena leucocephala* (from the Fabaceae family), exhibit a high potential for plastic entrapment, exceeding 75%. The Ficus genus, which thrives in the riparian zones of the Bedog River, predominantly takes the form of shrubs with a multi-branched growth architecture and a plant height of less than one meter. Species with a highly branched structure facilitate plastic entanglement

Journal of Biotechnology and Natural Science
Vol. 5, No. 1, June 2025, pp. 21-32
E-ISSN 2808-2508

(Gallitelli et al., 2024). *Pontederia crassipes*, or water hyacinths (Figure 4c), were found in sampling plots with slow-moving or even stagnant water, such as in river dams. The likelihood of this plant trapping plastic reaches 100%. Water hyacinths, which grow in colonies, often trap large plastic items such as used bottles or plastic bags containing household waste. The ability of water hyacinths to trap plastic was also recorded in the Saigon River, Vietnam, with a trapping capacity ranging from 54% to 77% across all sampling plots (Schreyers et al., 2024).

Table 2. The twenty most frequently identified species and their capacity to entrap plastic debris in the riparian zone of the Bedog River

Species Name	**Habit**	**Number of plots where the species trapped plastic / number of occurrence plots**	**Plastic entrapment probability**
Bambusa spinosa Robx.	giant grass	13/14	93%
Cenchrus purpureus (Schumach.) Morrone	grass	12/12	100%
Dendrocalamus asper (Schult.f.) Backer	giant grass	9/11	82%
Bambusa vulgaris Schrad. Ex J.C.Wendl.	giant grass	8/8	100%
Ficus hispida L.f.	shrub	7/7	100%
Leucaena leucocephala (Lam.) de Wit	shrub	6/8	75%
Dendrocalamus giganteus Munro	giant grass	6/6	100%
Cissus verticillata (L.) Nicolson & C.E. Jarvis	herb	5/13	38%
Urochloa mutica (Forssk.) T.Q.Nguyen	grass	5/8	63%
Saccharum officinarum L.	grass	5/5	100%
Macaranga tanarius (L.) Mull.Arg	shrub	4/5	80%
Ficus septica Burm.f.	shrub	4/5	80%
Tectona grandis L.f.	tree	4/4	100%
Bambusa multiplex (Lour.) Raeusch. ex Schult.f.	giant grass	4/4	100%
Pontederia crassipes Mart.	herb	4/4	100%
Musa x paradisiaca L.	tree	3/13	23%
Cyperus alterniflorus R.Br.	grass	3/7	43%
Syngonium podophyllum Schott	herb	2/13	15%
Colocasia esculenta (L.) Schott	herb	2/11	18%
Pterocarpus officinalis Jacq.	tree	2/4	50%

Syngonium podophyllum (Figure 4d), and *Colocasia esculenta*, belonging to the Arecaceae family, are consistently present across all plots but demonstrate a low plastic entrapment potential, below 20%. This is likely due to their soft-stemmed nature, with stem diameters of less than 3 cm, and relatively wide spacing between individual stems, which reduces the likelihood of plastic litter becoming ensnared. The plastic debris likely to be trapped by Arecaceae species is generally large in size, such as discarded bottles, as observed in Figure 4d. A similar pattern is observed in *Musa × paradisiaca* (Musaceae), where the relatively large spacing between its pseudostems results in a lower capacity for plastic retention. *Cissus verticillata* (Vitaceae), with a plastic entrapment potential of 38%, is a climbing plant that frequently attaches to bamboo vegetation (Figure 2c). Its positioning consistently above the river's water level means that only the vines that extend into the water surface have the capacity to capture plastic debris.

Figure 4. (a) *Bambusa spinosa* (Poaceae), (b) *Ficus hispida* (Moraceae), (c) *Pontederia crassipes* (Pontederiaceae), (d) *Syngonium podophyllum* (Arecaceae) entrapping plastic debris

Herbaceous plants (37%) and trees (32%) are the most prevalent life forms responsible for entrapping plastic debris in the riparian zone of the Bedog River, followed by shrubs (16%), grasses (10%), and giant grasses (5%) (Figure 5). Herbaceous riparian vegetation is evenly distributed across all plots, with 59 out of 95 riparian species in the Bedog River classified as herbaceous, and 30 of these species exhibiting plastic entrapment capabilities. Many of the identified herbaceous species belong to the Asteraceae, Euphorbiaceae, Araceae, Cucurbitaceae, and Vitaceae families. Plastic debris is frequently ensnared within dense herbaceous vegetation, particularly on leaves and rhizomes (Figures 6, 7a). Among tree species that contribute to plastic entrapment, the most common belong to the Moraceae, Fabaceae, Polypodiaceae, Musaceae, and Sapindaceae families. Notably, *Tectona grandis* (Lamiaceae) and *Pterocarpus officinalis* (Fabaceae) often trap plastic debris within their root systems, which become exposed due to soil erosion caused by water flow (Figure 7c). Additionally, identified shrub species exhibit highly branched structures (Figures 4b, 7b), with these branches serving as dominant sites for plastic accumulation, where debris is likely to remain trapped for extended periods. Field observations suggest that shrubs and bamboo have a greater capacity for plastic entrapment in riparian zones compared to herbaceous plants, trees, and grasses. This is further supported by the calculation of the average percentage of plastic entrapment probability across all species classified as giant grasses, which reaches approximately 95%, followed by shrubs at around 91%, grasses at 81%, trees at 80%, and herbs at 75%. However, this study has not yet accounted for the density and dominance of all vegetation within each plot. The current research only records the presence of species found within a plot as individual data points. Future research could be developed by calculating diversity levels and entrapment capacity, as demonstrated by Gallitelli using the 3DVI method (Gallitelli et al., 2024). Alternatively, spatial analyses could be conducted using remote sensing technology, Geographic Information System (GIS), or Unmanned Aerial Vehicles (UAVs). This study serves as an initial step toward highlighting the role of riparian vegetation, which could be optimized as plastic waste hotspots in freshwater ecosystems, contributing to early-stage mitigation before plastic pollution reaches the oceans. Future research also should quantitatively assess the abundance of plastic retained by each plant life form to provide more precise data for prioritizing vegetation-based mitigation strategies for plastic debris removal in riparian ecosystems. Since rivers serve as major conduits for land-based plastic waste transport to marine environments, reducing plastic accumulation in riparian areas is crucial for mitigating downstream pollution (Bruge et al., 2018).

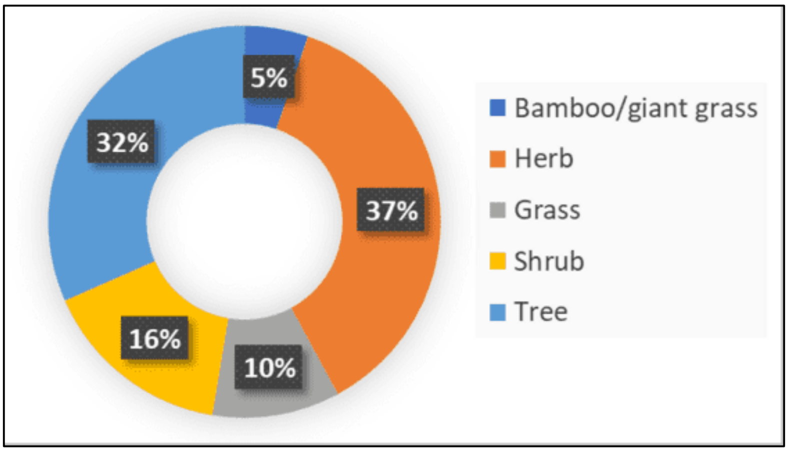

Figure 5. Distribution of vegetation habits entrapping plastic debris in the riparian zone of the Bedog River

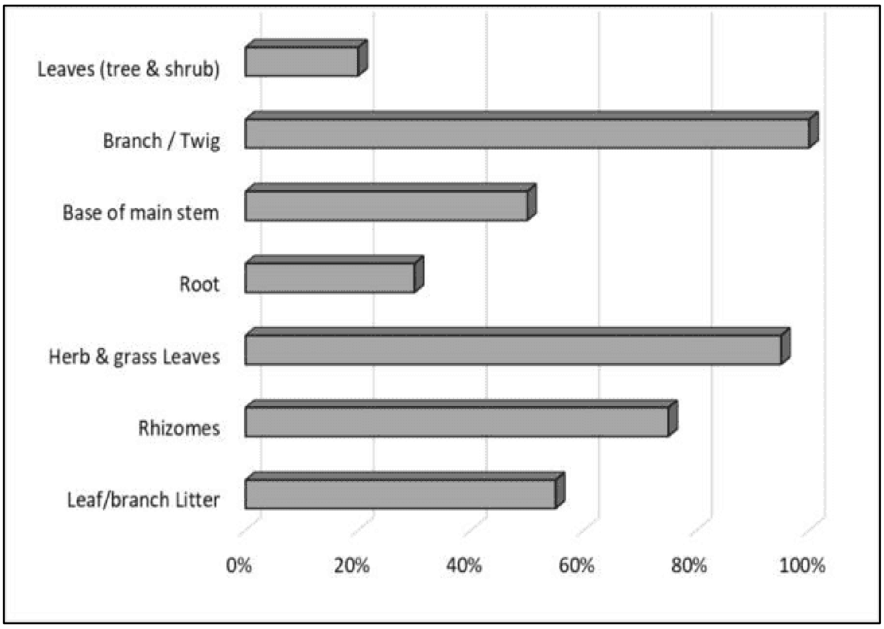

Figure 6. Plant structures involved in plastic debris entrapment

Figure 7. Plant structures capable of entrapping plastic debris: (a) herbaceous leaves and grass rhizomes, (b) branches/twigs, (c) basal stems and roots

The most commonly trapped plastic debris within vegetation consists of fragmented plastic pieces, often torn and difficult to identify in their original form (Figures 8, 9a). These fragments are likely derived from single-use plastic bags (*plastic kresek*), which are widely used in Indonesia and rarely recycled. Such waste may enter river ecosystems through rainwater runoff, flooding, or direct disposal into the river due to a lack of public environmental awareness. The strong river currents during the rainy season can further shred trapped plastic debris into smaller pieces, which get caught on parts of the plant and can remain there for a long time when the water flow slows down (Cesarini & Scalici, 2022; Gallitelli et al., 2023; Gallitelli & Scalici, 2024). Single-use plastic bags are typically trapped by roots or branches of riparian vegetation within a short distance (<10 meters) from their initial point of disposal (Ivar do Sul et al., 2014). Another frequently observed type of plastic waste includes multilayer sachets from food seasonings, shampoo packaging, and disposable diapers discarded into the river (Figure 9b). These materials are relatively thick, making them more recognizable and less fragmented. The Indonesian government has reported that 57% of the country's plastic production is dedicated to sachet packaging, yet only 10% is successfully recycled or processed (Indonesian Ministry of Environment and Forestry, 2020). Discarded plastic bottles and cups are often trapped within dense herbaceous vegetation. Additionally, large plastic bags containing household waste are often found in the riparian zone of the Bedog River (Figure 9c). According to brief interviews with local residents who dispose of waste in the riparian area, some do so because municipal authorities do not collect their garbage, while others refuse to pay waste collection fees, instead relying on the strong river currents during the rainy season to carry their waste downstream into the ocean. This detrimental practice among communities living along the riverbanks poses a significant threat to riparian, riverine, and marine ecosystems.

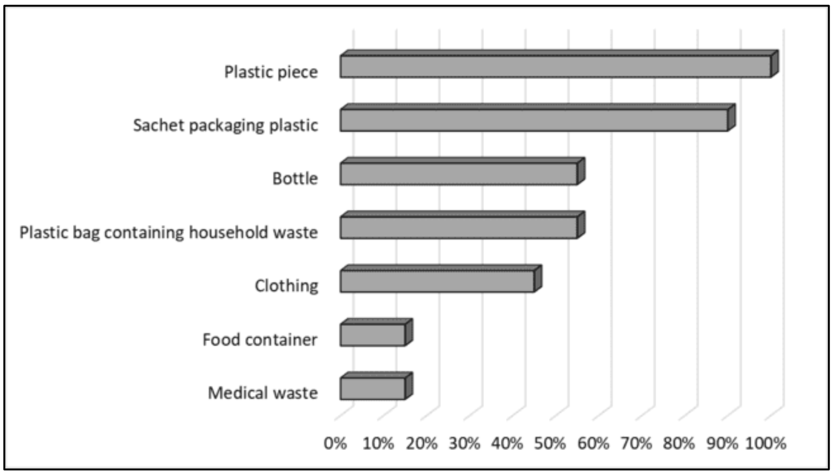

Figure 8. Types of plastic debris trapped in riparian vegetation of the Bedog River

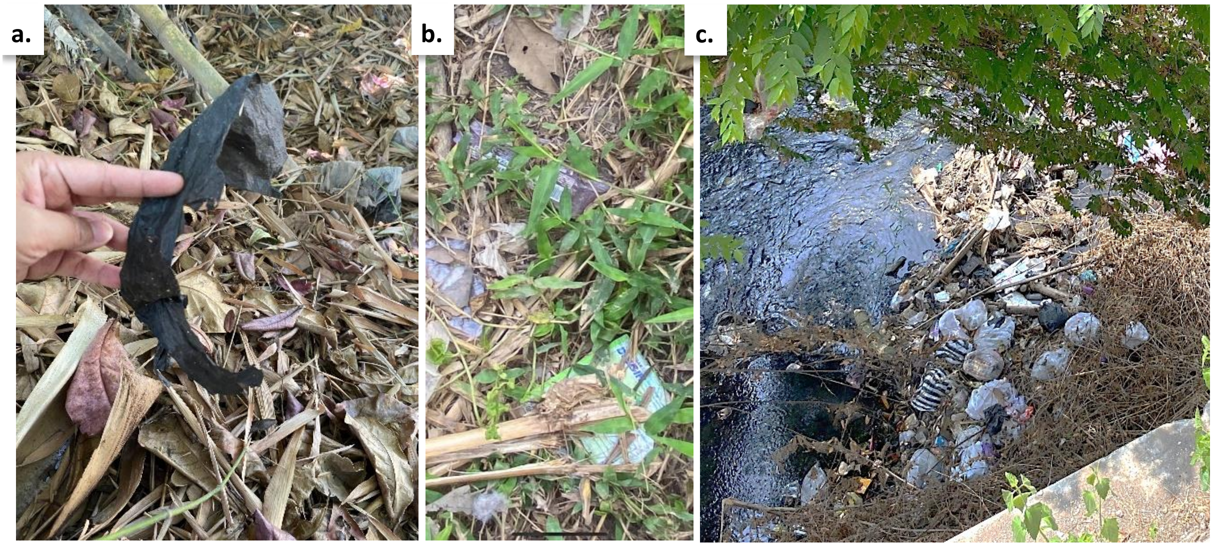

Figure 9. Fragmented plastic pieces (a), multilayer sachet packaging (b), and plastic bags containing household waste (c) commonly trapped in vegetation

4. Conclusion

The Bedog River, with an average width of 3.26 ± 1.28 meters, is predominantly lined with bamboo along its riparian zone. A total of seventy-eight plant species from 38 families have been identified as plastic debris traps, with most of the debris accumulating on their branches and twigs as well as herb leaves. The Poaceae family, which includes bamboo (*Bambusa spinosa*, *Dendrocalamus asper*, *Bambusa vulgaris*) and grasses (*Cenchrus purpureus*), along with the Fabaceae (*Leucaena leucocephala*) and Moraceae (*Ficus hispida*) families, primarily composed of shrub-like species, are the most effective in trapping plastic debris in the riparian zone of the Bedog River. The most frequently entrapped type of plastic is fragmented plastic pieces. Bamboo and shrubs possess distinctive structural characteristics that facilitate plastic entrapment, particularly on their branches and twigs, making them highly effective in capturing plastic debris.

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